Is there a limit to how many elements can be made?

Bezverkhniy Volodymyr Dmytrovych, Bezverkhniy Vitaliy Volodymyrovich.
Ukraine, e-mail: bezvold@ukr.net

Yes. There can be no more than 137 elements. This limitation of the number of elements follows from the fact that there is a maximum speed in the Universe. That is, from the limit of the speed of light in a vacuum. Moreover, this can be shown using only Bohr's model of the atom [1] and de Broglie's wave-particle dualism [2].

It should be noted that quantum mechanics never comes into conflict with classical physics. Quantum mechanics studies phenomena of a more complex order than classical physics, and these phenomena often have no figurative analogs in the macrocosm. For example, according to classical laws, an electron moving around a nucleus must fall on the nucleus of an atom. And since atoms exist, the wrong conclusion is made that the laws of classical physics in atoms are violated. But this is not true. Classical laws are unshakable. The electron does not fall on the nucleus of the atom, since the electron is not a corpuscle. It is because of the existence of wave-particle dualism that the electron does not fall on the nucleus. If the electron were a corpuscle, that is, a particle with a certain radius, it would inevitably fall on the nucleus. The classical laws in the atom work, but the electron is no longer an ordinary classical particle, therefore its behavior is different. This is a very important point for understanding quantum mechanics and further presentation.

Therefore, when we consider Bohr's model of the atom, we assume that the electron moves like a particle in an orbit around the nucleus. Taking into account Bohr's complementarity principle [3], an electron can be regarded as a particle, and all the characteristics obtained in this consideration will be correct (some clarification is needed that this is an elementary particle). But, the electron can manifest itself as a wave. That is why, again applying the principle of complementarity, we must take into account the wave characteristics of the electron. And only by combining the corpuscular and wave description, we can obtain comprehensive information about this phenomenon. That is, about the motion of an electron around the nucleus. Moreover, we note once again that all the characteristics obtained from such calculations are correct and correspond to reality (speed, wavelength, etc.). Thus, according to Bohr's theory, an electron moving around a nucleus has a certain speed. From here it is easy to get a limit on the number of chemical elements in the periodic system of D. I. Mendeleev [4]: the speed of a 1S-electron when moving around the nucleus of an atom cannot be higher than the speed of light in vacuum.

We especially note that you need to understand that, strictly speaking, an electron in an atom has no trajectory. Since the classical understanding of velocity in the general case is not applicable to an electron in an atom. But, if we follow the principle of complementarity, then the speed of the electron as a corpuscle is correct. Therefore, no matter what quantum state the electron will be in, it is sometimes obliged to manifest itself as a corpuscle (since there is a particle-wave dualism). This means that the speed of such a "corpuscle" must be less than the speed of light. If the speed turns out to be higher than the speed of light in vacuum, then such a state of an electron cannot exist in principle. That is why, using the Bohr model of the hydrogen atom, one can obtain correct results for the speed of the 1S-electron. Naturally, if the speed of an electron is higher than the speed of light in a vacuum, then such a chemical element cannot exist by definition.

In this calculation, the atomic nucleus is assumed to be pointlike. For the hydrogen atom, this is true. But, nuclei with a large number of protons can no longer be considered pointlike. Moreover, the size of the nuclei, their shape, as well as the distribution of charge over the surface of the nuclei are well studied experimentally. And therefore, the question arises: is it necessary to accurately recalculate the electron velocity taking into account the real dimensions of the nucleus? Before answering, remember that strictly speaking, an electron in an atom has no trajectory. An electron in an atom, within the 1S-orbital, appears and disappears with a certain frequency and with certain characteristics. There is a certain probability of finding an electron in a given region of space. No more. In fact, we observe a kind of "pulsation" of an electron, if we imagine it as a corpuscle. Let us also take into account the fact that nuclei, by definition, cannot be motionless, since they are quantum particles. That is, the electric field emanating from the nucleus (and acting on the electron) will be averaged over time. This means that taking into account the exact size of the nuclei is not needed, since the electric field is spherically symmetric and changes according to the 1/r^2 law. And therefore, the calculation, taking into account the fact that the kernel is assumed to be pointwise, is absolutely correct, and does not require any clarifications.

So, consider a point nucleus, which has a charge Z. Around this nucleus in the first Bohr orbit, an electron moves with a certain velocity v. Taking into account Newton's second law and Coulomb attraction, it is easy to get the dependence of the speed from the charge of the nucleus.

$$(m * v^2) / 2 = (k * e^2 * Z) / 2$$

$$v^2 = (k * e^2 * Z) / (m * r)$$

where r - is the radius of the first Bohr orbit,

m - is the electron mass,

v - is the speed of an electron in the first Bohr orbit,

e - is the electron charge,

k - is the corresponding constant from Coulomb's law.

Let us take into account relativistic effects in the last formula. That is, the fact that when the electron moves, its mass will increase. Then we get the equation:

$$v^2 = (k * e^2 * Z) / (m0 * r * \gamma)$$

where m0 - is the rest mass of an electron,

γ - Lorentz factor [5],

$\gamma = 1 / (1 - v^2/c^2)^{0.5}$

But, it is also necessary to take into account the fact that the radius of the Bohr orbit decreases with an increase in the speed of the electron. It is known that the length of the Bohr orbit is equal to the de Broglie wavelength (here is the wave description!). Therefore, as the electron speed increases, the de Broglie wavelength will decrease.

$$\lambda = 2 * \pi * r = h / (m * v)$$

where λ - de Broglie wavelength,

v - electron speed

m - is the electron mass.

When calculating the de Broglie wavelength, we must take into account the relativistic increase in the electron mass. Therefore, the radius of the Bohr orbit, taking into account relativistic effects, will be equal to:

$$r = \hbar / (m0 * v * \gamma)$$

where γ - is the Lorentz factor,

m0 - is the rest mass of an electron,

v - is the speed of the electron,

Planck's constant $\hbar = h / (2 \times \pi) = 1.054571 \times 10^{(-34)}$ J × s.

We use this radius in the formula:

$$v^2 = (k * e^2 * Z) / (m0 * r * \gamma)$$

$$r = \hbar / (m0 * v * \gamma)$$

As a result, we obtain a relativistic formula for calculating the speed of an electron in the first Bohr orbit of any nucleus:

$$v = (k * e^2 * Z) / \hbar$$

It is especially important for us that the formula is relativistic, since we need to determine the charge of the atomic nucleus, at which the speed of the electron will be equal to the speed of light in vacuum.

$$v = (k * e^2 * Z) / \hbar$$

$$Z = (\hbar * v) / (k * e^2)$$

$$Z = (\hbar * c) / (k * e^2)$$

Substituting the constants into the last formula, we obtain the nuclear charge equal to 137.036, at which the speed of the electron in the Bohr orbit is equal to the speed of light in vacuum.

$$Z = (\hbar * c) / (k * e^2) = 1 / \alpha = 137.036$$

where α - is a fine structure constant [6].

Thus, if we have a nucleus with a charge of 137 (Z = 137), then the 1S-electron in the first Bohr orbit will have a speed slightly lower than the speed of light in vacuum. The existence of a chemical element with a nucleus charge of 138 is no longer possible, since the speed of the 1S-electron will already be greater than the speed of light in vacuum. This is impossible. Therefore, a chemical element with Z = 137 is the theoretical limit of the periodic table of elements of D. I. Mendeleev [7]. It is sometimes called Feynmanium.

«It is a "folk legend" among physicists that Richard Feynman suggested that neutral atoms could not exist for atomic numbers greater than Z = 137, on the grounds that the relativistic Dirac equation predicts that the ground-state energy of the innermost electron in such an atom would be an imaginary number. Here, the number 137 arises as the inverse of the fine-structure constant. By this argument, neutral atoms cannot exist beyond untriseptium, and therefore a periodic table of elements based on electron orbitals breaks down at this point. However, this argument presumes that the atomic nucleus is pointlike. A more accurate calculation must take into account the small, but nonzero, size of the nucleus, which is predicted to push the limit further to Z ≈ 173 [76]» [8, 76. Philip Ball (November 2010). "Would element 137 really spell the end of the periodic table? Philip Ball examines the evidence". Chemistry World. Royal Society of Chemistry].

At this point in time, the periodic table ends with the element Oganesson [9] with a nucleus

charge equal to 118 (Og, Z = 118). This element is named Oganesson (Og) after the Soviet and Russian chemist Yuri Oganessian [10, born in 1933] for his pioneering contributions to the synthesis of new elements. Yuri Oganesyan became the second scientist after Glenn Seaborg [11], during whose lifetime a chemical element was named after him.

Let's determine the speed of the 1S-electron in Oganesson, as well as the radius of its first Bohr orbit. For this, the above equations will be written in a more convenient form.

$$v = 2.19 * 10^6 * Z$$

$$r = 0.529 * 10^{(-10)} / Z$$

From where, we get the results for Oganesson (Og, 118).

$$v\ (Og) = 2.58 * 10^8\ m/s = 0.86 * c$$

$$r\ (Og) = 0.448 * 10^{(-12)}\ m$$

Next, let's calculate the speed and radius for Fermiya (Fm, Z = 100).

$$v\ (Fm) = 2.19 * 10^8\ m/s = 0.73 * c$$

$$r\ (Fm) = 0.529 * 10^{(-12)}\ m$$

Starting from Fermiya (Z = 100) and further, the speed of an electron in the first Bohr orbit begins to approach the speed of light in a vacuum. The half-life of these elements (Z = 100, and beyond) also drops [12]. Moreover, a decrease in the half-life (of the longest-lived isotope) actually occurs from element to element (with slight fluctuations). Up to Z = 100, the variation in the half-life of the elements was virtually arbitrary. But when the speed of the electron began to approach the speed of light, the decrease in the half-life became natural. That is, the higher the nuclear charge, the lower the half-life of the longest-lived isotope. Look at the picture that demonstrates this [12].

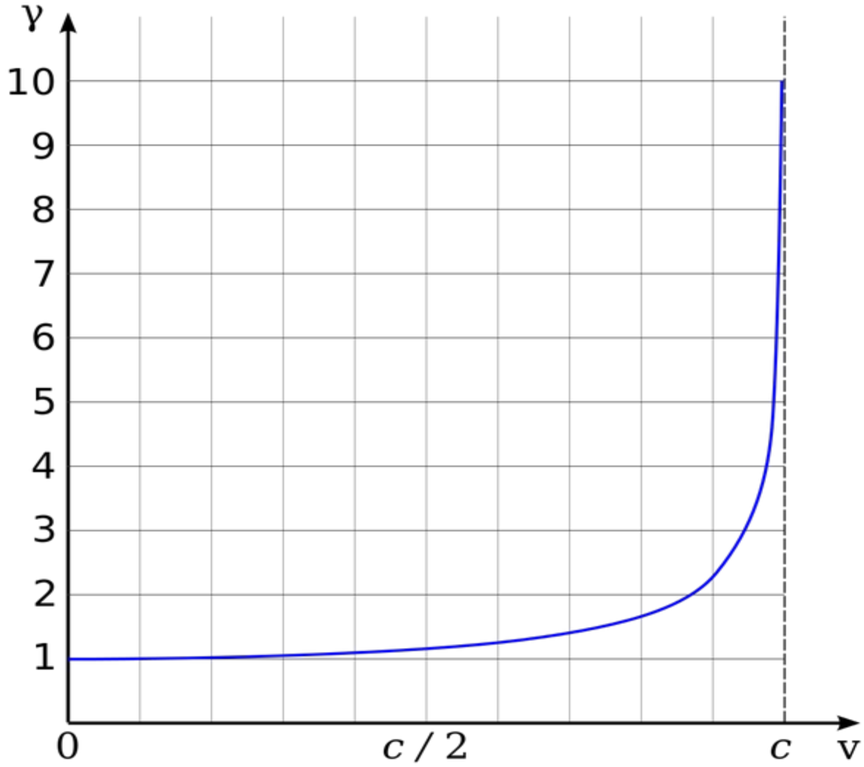
Most stable isotopes of superheavy elements ($Z \geq 104$)

Element	Atomic number	Most stable isotope	Half-life[d]	
			Publications [34][35]	NUBASE 2016 [36]
Rutherfordium	104	^{267}Rf	1.3 h	2.5 h
Dubnium	105	^{268}Db	1.2 d	1.1 d
Seaborgium	106	^{269}Sg	14 min[37]	5 min
Bohrium	107	^{270}Bh[e]	1 min	3.8 min
Hassium	108	^{269}Hs	9.7 s[39]	16 s
Meitnerium	109	^{278}Mt[f][g]	4.5 s	7 s
Darmstadtium	110	^{281}Ds[f]	12.7 s	14 s
Roentgenium	111	^{282}Rg[f][h]	1.7 min	1.6 min
Copernicium	112	^{285}Cn[f]	28 s	32 s
Nihonium	113	^{286}Nh[f]	9.5 s	7 s
Flerovium	114	^{289}Fl[f][i]	1.9 s	2.4 s
Moscovium	115	^{290}Mc[f]	650 ms	410 ms
Livermorium	116	^{293}Lv[f]	57 ms	80 ms
Tennessine	117	^{294}Ts[f]	51 ms	70 ms
Oganesson	118	^{294}Og[f][j]	690 μs	1.15 ms

Interest in a possible island of stability grew througho as some calculations suggested that it might contain half-lives of billions of years.[41][42] They were also pr especially stable against spontaneous fission in spite atomic mass.[31][43] It was thought that if such elemer are sufficiently long-lived, there may be several novel as a consequence of their nuclear and chemical prop include use in particle accelerators as neutron source weapons as a consequence of their predicted low crit and high number of neutrons emitted per fission,[44] a fuel to power space missions.[33] These speculations researchers to conduct searches for superheavy elen 1960s and 1970s, both in nature and through nucleos particle accelerators.[22]

During the 1970s, many searches for long-lived supe were conducted. Experiments aimed at synthesizing ranging in atomic number from 110 to 127 were cond laboratories around the world.[45][46] These elements fusion-evaporation reactions, in which a heavy target nuclide is irradiated by accelerated ions of another in and new nuclides are produced after these nuclei fus

It is quite obvious that this is due to the relativistic effects of the 1S electron. This is clearly seen if you look at the graph of the dependence of the Lorentz factor from speed [5].



From the figure it is obvious that starting from a speed of 0.6*c to 0.8*c, the Lorentz factor began to grow rapidly. Moreover, starting from 0.8*c, the increase in the Lorentz factor has become much more rapid. Therefore, there were such difficulties in the synthesis of Oganesson (Og, 118, v = 0.86 * c). It is evident from the graph that a decrease in the half-life of elements correlates with an increase in the 1S-electron relativism. Consequently, elements with a large nuclear charge than 118 will have a half-life even less, since the relativism of the electron will greatly increase. This means that the synthesis of the next new elements will be extremely difficult. Therefore, Feynmanium (Z = 137) is indeed the last chemical element in the periodic table, and the dependence of the Lorentz factor from speed clearly confirms this.

1. Bohr model. Wikipedia. https://en.wikipedia.org/wiki/Bohr_model
2. Wave–particle duality. Wikipedia. https://en.wikipedia.org/wiki/Wave%E2%80%93particle_duality
3. Complementarity (physics). Wikipedia. https://en.wikipedia.org/wiki/Complementarity_(physics)

4. Periodic table. Wikipedia. https://en.wikipedia.org/wiki/Periodic_table
5. Lorentz factor. Wikipedia. https://en.wikipedia.org/wiki/Lorentz_factor
6. Fine-structure constant. Wikipedia. https://en.wikipedia.org/wiki/Fine-structure_constant
7. Dmitri Mendeleev. Wikipedia. https://en.wikipedia.org/wiki/Dmitri_Mendeleev
8. Extended periodic table. Wikipedia. https://en.wikipedia.org/wiki/Extended_periodic_table#Elements_above_the_atomic_number_137
9. Oganesson. Wikipedia. https://en.wikipedia.org/wiki/Oganesson
10. Yuri Oganessian. Wikipedia. https://en.wikipedia.org/wiki/Yuri_Oganessian
11. Glenn T. Seaborg. Wikipedia. https://en.wikipedia.org/wiki/Glenn_T._Seaborg
12. Island of stability. Wikipedia. https://en.wikipedia.org/wiki/Island_of_stability
13. Is there a limit to how many elements can be made? Quora. https://qr.ae/pNsDgf